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DESIGN AND DEVELOPMENT OF
VARIABLE-LOAD ENERGY ABSORBERS

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constricting mechanism, and a hydraulic energy absorber. Preliminary full-scale working models of the wire-bending mechanism and the tube-constricting mechanism were built and tested. The hydraulic energy absorber was evaluated via a computer simulation. Different adjustment and control concepts were also evaluated.

The tube-constricting mechanism was found to offer the best combination of features and was therefore selected for further prototype development. The prototype variable-load energy absorber utilized an inversion tube process to supply a fixed load sized for the lightest occupant. Additional variable load was supplied for heavier occupants by the tube-constricting mechanism which further deformed the inverted tube. Energy absorbers of this type, together with a remote control selector dial coupled to the energy absorbers by flexible shafts, were installed on an SH-60B crewseat for evaluation in a series of dynamic tests.

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1.0 INTRODUCTION

Because of the relatively low tolerance of the human body to forces parallel to the spine, survivable helicopter accidents, in which sufficient living space is maintained by the airframe structure, may impose injurious forces in the vertical direction. Because insufficient crush space is available within the floor structure of helicopters and light aircraft, the seat must play a significant role in attenuating these potentially injurious forces to tolerable levels. Recently developed helicopters such as the U.S. Navy's SH-60B Seahawk and the U.S. Army's UH-60A Black Hawk and AH-64A Advanced Attack Helicopter are equipped with seats that have built-in vertical energy-absorption systems.

Presently, fixed energy absorber limit loads are set for the 50th-percentile occupant, under the crash conditions of the 95th-percentile survivable accident. A heavy (e.g., 95th-percentile) occupant in the same crash conditions may bottom out at the end of the stroking distance. Conversely, a light (e.g., 5th-percentile) occupant will not be able to take advantage of the full stroking distance available and will be subjected to accelerations of higher magnitude than desirable.

The objectives of this program were to analyze, design, develop, and test variable-load energy absorber concepts. The development of variable-load energy absorbers will make it possible for the limit load of an energy-absorbing seat to correspond to the occupant's weight, thus providing optimum crash protection within a given fixed stroking distance.

This report describes the efforts undertaken by Simula Inc. to achieve the above-stated objectives under Contract No. N62269-79-C-0241 for the Naval Air Development Center. The major concepts investigated were the wire-bender energy absorption system, a passively controlled hydraulic energy absorber, and energy absorption via additional deformation of an inversion tube.

The following sections present the requirements, applied criteria, design, development, and testing of the selected variable-load energy absorber concepts and methods of variability control.

2.0 DEFINITION OF TERMS

The following text defines key words used in this report which might not otherwise be familiar to the reader.

Energy Absorber (E/A), Load Limiter,
Load Limiting Device, Attenuator

These are interchangeable names of devices used to limit the load structure to a preselected value. These devices absorb energy by providing a resistive force applied over a deformation distance without significant elastic rebound.

Limit Load

In a structure, limit load refers to the load the structure will carry before yielding. Similarly, in an energy absorbing device, it represents the load at which the device deforms in performing its function.

Companion Energy Absorber

In a variable-load energy absorber, the total limit load may be the sum of the loads from two sources, one source being a fixed primary energy absorber, the other being a variable-load energy absorber. In such a case the fixed-load energy absorber is said to be the companion of the variable-load energy absorber.

Occupant Vertical Effective Weight

This is the portion of occupant weight supported by the seat with the occupant seated in a normal flight position. This is considered to be 80 percent of the occupant weight, plus equipment and clothes carried above the knees, since the weight of the feet, boots, lower legs, and part of the thighs is carried directly by the floor through the feet.

Incremental Control

This is a means of limit load control on an energy absorbing device through engagement or disengagement of mechanisms in discrete increments, e.g., engagement of different numbers of wires in a wire-bending type energy absorber.

Infinite Control

This is a means of limit load control through which continuous adjustment can be made throughout a specified range.

Normal Force

Normal force is defined as force in a direction which presses friction surfaces together.

3.0 REQUIREMENTS AND ASSUMPTIONS

The variable-load energy absorber program was required to comply with the following conditions:

- The variable-load energy absorber was required to be designed for the 5th- through 95th-percentile occupants exposed to the 95th-percentile survivable crash pulse in the vertical direction.
- At the time this program was begun, criteria specified a 14.5-G vertical limit load as an optimum for the range of occupant size. For purposes of this study, possible differences in dynamic response and deceleration tolerance among occupants of different weight were neglected.
- Energy absorber limit load could be varied continuously over the range required to decelerate 5th- through 95th-percentile occupants at 14.5 G. Alternatively, as few as three discrete levels could be selected to cover that range in three bands.
- Control of the energy absorber could require either conscious action on the part of the occupant (active system) or no action (passive). Emphasis was to be placed upon active systems.
- Electronic devices were not to be used as part of the weight-sensing or control mechanisms.
- The variable-load energy absorber concepts were required to be retrofittable to crewseats in the SH-60B (LAMPS) Seahawk, UH-60A Black Hawk, and AH-64A Advanced Attack Helicopters.

4.0 VARIABLE LOAD ENERGY ABSORBING CRITERIA

4.1 DESIRABLE CHARACTERISTICS

Many concepts were brought forth during brain-storming sessions, and each was evaluated in terms of the following desired characteristics:

- **durability**
 - Is it sufficient?
- **Adjustability**
 - How?
 - With what ease?
 - Continuous or incremental?
- **Low Technical Risk**
 - What is the probability of developmental success?
 - Analytical or empirical?
 - Deadband model required?
- **Reliability**
 - Projected Mean Time Between Failures?
 - Reliability?
 - Fail-safe?
 - Vibration resistance?
- **Low Cost**
- **Low Weight**
- **Compliance**
- **Support Rebound Load**
 - by itself?
 - Not degrade damping energy absorber?
- **Accuracy**
 - Prediction of adjustment?
 - Agreement of actual load with predicted desired load?
 - Time dependence (dwell)?
- **Constant load throughout stroke**
 - High initial elastic efficiency?
 - Flat plateau in plastic region?
 - Rate sensitivity, dynamic/static?

4.2 DESIGN CRITERIA

The following criteria were considered in the design of the system:

- Interchangeability of energy absorbers.
- Configuration modification of energy absorber (i.e., it is not desirable to change the stroking length by any appreciable amount or the fixed length between the rod ends which are the attachment points for the device).
- Clearance for the actuation mechanism at the energy absorbers and at the occupant control, taking into consideration the surrounding area and the stroking and vertical adjustment of the bucket.
- Occupant control location. Control should be easily accessible and adjustable either by feel (incremental) or by sight (infinite).
- Calibration of control system (i.e., synchronization of both E/As with each other and with the control adjustment to ensure the accuracy of the desired load and the load delivered).
- Simplicity, i.e., keeping parts simple and to a minimum.
- Use of standard items wherever possible, thus minimizing the manufacturing costs.
- Packaging of the variable-load energy absorbers within the volume of the existing fixed-load energy absorbers.
- Ease of assembly (production).
- Retrievability of energy absorbers in the field and ease of installation.
- Maintenance free or minimal periodic maintenance required.
- Low cost.
- Low weight.
- Dependability and reliability.

4.2.1 Friction Versus Plastic Deformation

Energy absorber concepts which rely heavily upon friction have been shown in the past to be unreliable. Unacceptable load variations result from changes in friction coefficient and normal force due to changing conditions of surface finish, lubricants, contaminants, aging, vibration fretting, corrosion, and tolerances.

All concepts which were considered emphasized plastic deformation. Friction forces, if present, were considered incidental to the design and were minimized.

5.0 CONTROL5.1 TYPES OF CONTROL

The original intention was to study two types of control systems, passive and active. These, and a third, hybrid system called active without selection (AWS), are discussed in the following text.

5.1.1 Passive Control

No action or even awareness on the part of the occupant would be required for a passive system. Compensation for the effective weight of the occupant, as well as his equipment, would be automatic.

5.1.1.1 Acceleration-Sensing Control. In a hydraulic energy absorber, automatic control could be accomplished by a deceleration-sensing servo valve used to throttle the flow of hydraulic fluid. A portion of the pressurized fluid within the energy absorber would be bled off and used to power the amplifier stage of the servo valve. The high frequency response of such a servo valve is a sufficiently difficult problem to be the sole subject of an extensive development program, and was outside the scope of this project. Also, a hydraulic cylinder, unless it is capable of telescoping by means of multiple concentric tubes or by a cable and pulley arrangement, could not provide the necessary stroke, and therefore was unsuitable for retrofit purposes.

No other practical acceleration-sensing control devices were envisioned. Inertia-operated mechanical devices were judged incapable of sufficient accuracy or frequency response.

5.1.1.2 Weight-Sensing Control. The effective weight of the occupant plus equipment could be sensed in the following locations:

- Seat cushion
- Vertical-adjustment mechanism
- Energy absorber(s).

If sensed at the cushion, the total weight must be computed as the integral of pressure over all contact area between the occupant and cushion. No practical means for meeting this requirement was conceived.

The sensing of weight at the vertical-adjustment mechanism would be desirable because relative motion and locking is already a feature provided by this device. Seats that have been designed by Simula Inc. have one single vertical-adjustment mechanism which joins both energy absorbers to the bucket, thus only one weight-sensing device is necessary to control both energy absorbers. This approach would be preferred for new seat designs; but was not desirable for this program, as retrofit would require extensive replacement of parts in the vertical-adjustment mechanism in addition to the energy absorbers.

The most suitable location for the weight sensor appeared to be upon one or both energy absorbers. The weight-sensing function would be performed by a spring device, the deflection of which is proportional to the downward force upon the bucket. Total movement on the order of 1/2 in. was considered. A problem with this system was that the net downward force upon the bucket may not be proportional to the desired mass parameter. Vibrations and flight loads resulting from maneuvers, or possibly even freefall, seconds before a crash may cause erroneous weight sensing. One method of preventing this would be to dampen the weight-sensing device. A very powerful viscous force would be necessary to prevent unwanted transient deflections, especially if the motion of the sensing device is less than 1/2 in.

Inaccuracies of deadband or hysteresis caused by ordinary mechanical friction in the control system were not considered to be a problem because of the presence of vibration.

In emergency situations where the seat becomes occupied a brief time before takeoff, the highly viscous damped control system may not reach equilibrium before takeoff of the aircraft.

An automatic inertia-operated locking feature is required of the control mechanism at the onset of a crash to prevent the control from being "fooled" into believing that the occupant is suddenly becoming more massive than he really is.

To date, the seats which Simula has manufactured have not been entirely free of friction during vertical adjustment. The roller bearings with which the bucket adjusts vertically may encounter slight irregularities in the guide tube on which they roll. There may also be a condition of contamination of the guide tubes with dirt and debris which would cause more undesirable friction and load. Any additional friction such as this is undesirable and would create a false interpretation of the actual load by the weight-sensing mechanism.

5.1.2 Active (Control) Without Selection (AWS)

In this scheme the limit load would be selected automatically, but the occupant would be required to lock that setting. This approach would prevent the occupant from either accidentally selecting an incorrect load or consciously subverting instructions in order to provide a limit load which he feels is "safer."

Once locked, the limit load would be unaffected by variations in net force on the weight-sensing device which might result from flight loads just prior to a crash, or from inertial loads at the onset of a crash. Friction such as discussed in Section 5.1.1.2 would still be a problem.

5.1.3 Active Control

An active control system would require an occupant to select an energy absorber load setting to correspond to his weight. This action would be performed during the preflight check by rotating a dial (infinite control) or positioning a lever (incremental control) located accessibly on the seat bucket or frame. The dial or lever would control both energy absorbers simultaneously through some type of linkage, most likely flexible shafting or flexible push-pull cable.

The single-point control for both energy absorbers is recommended over a system which would require adjustment of each energy absorber independently. The latter system would be clumsy because of the inaccessible position of the energy absorbers on the back of the seat.

Survival equipment carried on an occupant's body may alter the effective stroking weight significantly. It was therefore decided to permit the occupant to compensate for this variation in weight as he selects the proper limit load. His estimation of the weight of the equipment he carries may be a source of error of perhaps ± 5 lb.

5.1.3.1 Requirements for Active Control System. As indicated previously, the load-varying mechanism at the energy absorber would be controlled through flexible cable from a lever or dial located accessibly on the seat bucket. With this control system, accuracy of the input-output function through the cable becomes a consideration.

Some energy absorbers require control in discrete increments such as the engagement of different numbers of wires in a wire-bending or wire-drawing mechanism. For instance, a spring-loaded detent

could be provided for each increment at either the energy absorber or at the input lever or dial. It was found to be preferable to locate the detent at the energy absorbers in order to minimize the effect of inaccuracies in the control cable. For three or four increments of load, the pilot should be able to set the control input lever by feel without need for visual indexing.

For infinitely variable energy absorber controls, a method of visual indexing at the input end of the cable would be required.

This input index must be synchronized to the variable-load mechanism, requiring precise input-output motion. Push-pull flexible cable is not suitable for this because it is inherently imprecise even with spring preload to reduce the slack; for any given input position, the output position is dependent upon the radius and number of bends in the cable, as well as upon wear and/or damage. Also, spring preload may interfere with the fail-safe functioning of the control, that is, the ability of the control to maintain the selected load setting even though the lock of the input lever may have failed.

A more dependable method for transfer of infinitely variable limit-load demand is the utilization of rotary displacement through flexible shafting. At the input end, the flexible shaft could be turned through, say, five complete revolutions. At the output end, the flexible shaft would drive a worm or screw which would translate the rotary displacement into precise linear displacement. A mechanical detent or friction drag on the dial would prevent its setting from changing due to vibration.

The worm or screw drive mechanism coupling the cable to the variable-load mechanism is inherently capable of sustaining high reaction loads and cannot be back-driven, especially if the chosen lead angle is less than 5 degrees.

6.0 ENERGY ABSORBER CONCEPTS

Three major concepts were selected from among many possible for development and breadboard testing or computer simulation and design analysis: wire bender, hydraulic cylinder, and tube constrictor. These concepts are discussed more fully in the following sections.

6.1 WIRE BENDER

Previous research has involved energy absorbers whose loads were adjustable in steps (i.e., increments) by means of varying the number of wires engaged with the rolling mechanism. The tests conducted in this program verified that for a fixed set of conditions (i.e., wire diameter and roller positions) a predetermined load can be accurately attained by this method.

The wire-bending device is not capable of supporting compressive loads by itself except when packaged in such a way as to be too long for the intended retrofit application. For this reason, another device to supplement the wire bender was needed. The best choice appeared to be an inversion tube energy absorber, already qualified and in use on the seats of interest. In order to conserve space and to protect the wire bender, it was decided to package the wire bender inside the inversion tube.

For an incrementally adjustable energy absorbing system, the desired load can be achieved by engaging or disengaging wires which have been guided through and made to conform to a set of fixed rollers. For a specific wire diameter and set of fixed rollers, a unique load will be generated by pulling the wire(s) through the roller set. Because of the packaging restraints, the configuration of the fixed rollers is limited, but there is an option on the wire diameter which can be selected to give the desired load per wire for a given fixed roller configuration. The

specific wire diameter which will create the desired load per wire can be determined by testing.

The basis for the infinitely adjustable energy absorbing system is similar to that for the incrementally adjustable type. That is, for a certain wire diameter and roller configuration a specific load will be delivered from pulling the wires through the roller set. However, by fixing two rollers (i.e., top and bottom) and varying the center roller (by occupant control), the load can be altered. For each position of the variable roller a unique load, determined by the roller position, will be attained. This works well through a range of roller positions larger than that which was predicted analytically. Beyond that range no additional increase in load is possible because the wire, having conformed fully to the rollers' profile, is incapable of further deformation.

6.1.1 Wire-Bender Infinitely Adjustable Control

The infinitely adjustable wire-bender energy absorbing system is a feasible means of controlling the load by varying the adjustable roller position. However, packaging confinements create a problem in retrofitting the variable-load energy absorber system onto existing seats. A system was not found which would allow the clearance necessary for the adjustable roller to perform its function. In order to package the system inside the inversion tube, the stroking length and/or the overall length would change. Neither of these situations is desirable.

Due to this problem, the infinitely adjustable wire-bender energy absorber was considered to be less desirable than some other alternatives.

6.1.2 Wire-Bender Incrementally Adjustable Control

An incrementally adjustable wire-bender system is practical and can be accomplished within the package limitations (i.e., inside

the inversion-tube energy absorber). A system has been designed which will allow two wires to be incrementally engaged or disengaged individually using push-pull cables, thus providing three discrete increments of load (Figures 1 and 2). The smallest increment is that of the inversion tube acting alone.

There would be no increase in the envelope diameter of the energy absorber. There would be a projection from the lower end of the energy absorber where the push-pull control cable would enter the engagement system. Extra cable length could be provided to accommodate the vertical adjustment of the bucket. The 1.25-in. travel of the cable would have to be amplified by a lever at the control handle in order to provide ±1.0 in. of travel. A decal beside the control handle would instruct the occupant in its use. It is expected that crewmen familiar with the handle's use would set it by feel, much as they do with the inertia reel lock handle. A ball detent at the engagement pin would provide the occupant with a positive "feel" for each of the three engagement positions.

6.1.3 Incremental Wire-Engagement System

The wire-engagement system would be located at the lower end of the attenuator. In the event that the wire(s) were engaged by the engagement pin and the bucket stroked, they would be pulled through the roller package (Figure 2). The roller package would be fixed at the upper end of the attenuator (i.e., on the end of the inversion tube). The wires could be stored below the roller package in a helix or "S" shape.

A plastic sleeve would be used to hold the wire(s) in location when the engagement pin was at the position which would disengage the wire(s). In the instance that one or both wires were disengaged and the attenuator was stroked, the plastic sleeve would shear and the wire(s) would carry no load. The sleeve would also be useful in reducing the sliding friction of the engagement pin.

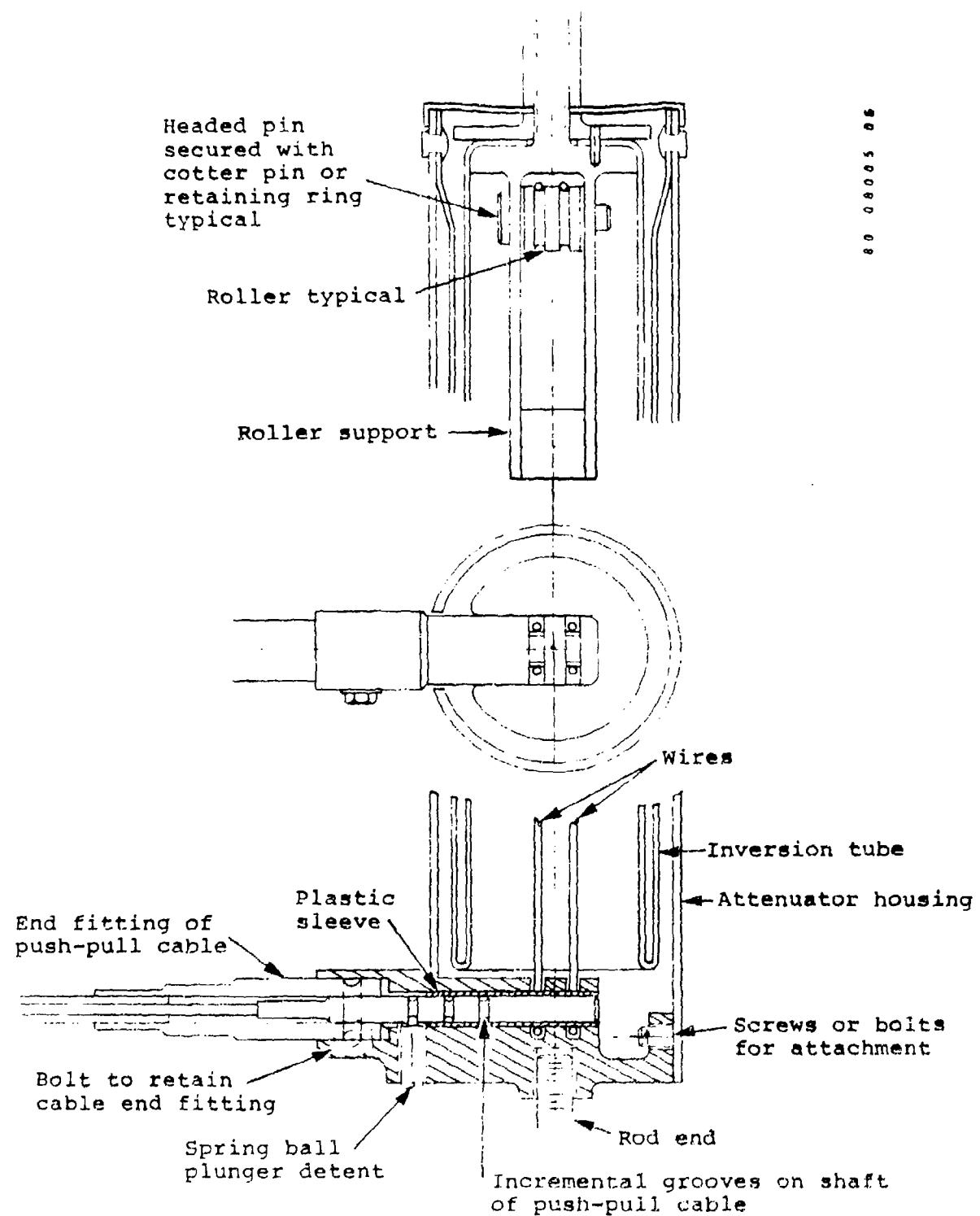


Figure 1. Incremental load achieved by engaging or disengaging wires.

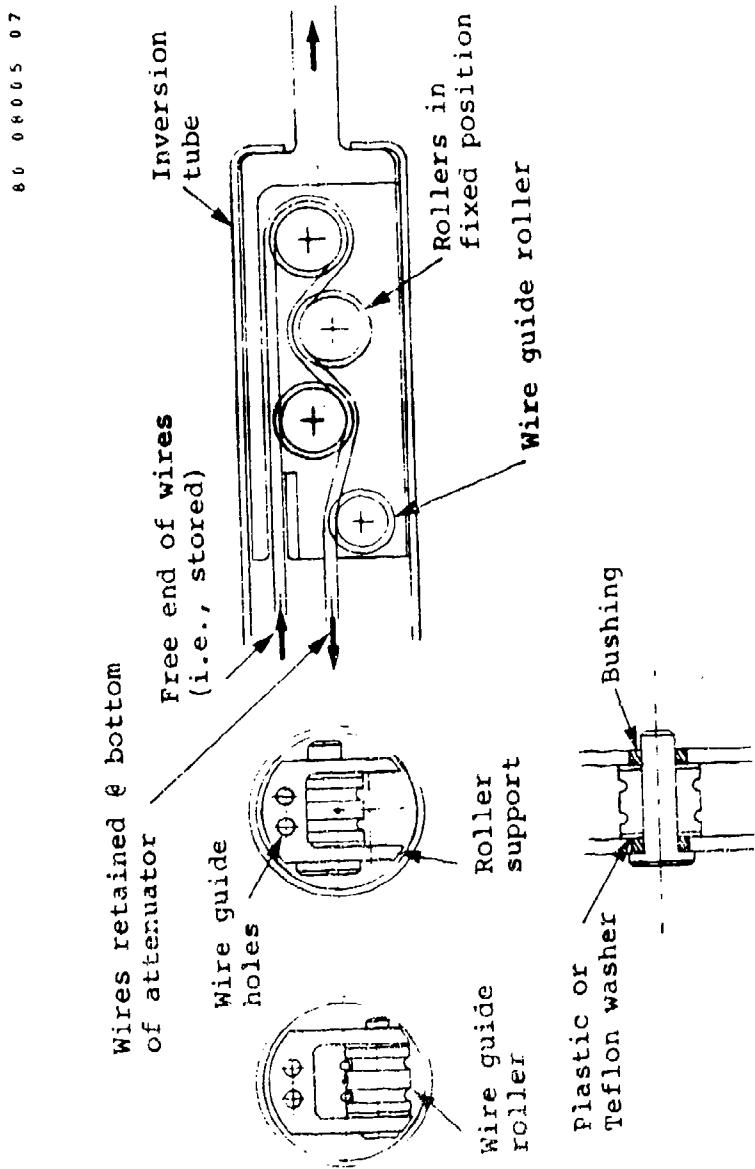


Figure 2. Roller package.

6.1.4 Results of Wire-Bender Energy Absorber Concepts

The incrementally adjustable wire bender is a practical solution, but because an incrementally adjustable system is inherently inferior to an infinitely adjustable system, work on the incrementally adjustable wire bender was discontinued in favor of the infinitely adjustable system described in Section 6.3.

As mentioned in paragraph 6.1.1, the infinitely adjustable wire bender is not well suited for retrofit purposes, and no further development on this system was performed.

6.2 PASSIVE HYDRAULIC ENERGY ABSORBER

The computer simulation of this device demonstrated that effective movable weights ranging from 141 to 220 lb could be decelerated at nearly the same rate (see Figure 3). This was only verified through 50 msec of the crash pulse. At 50 msec the input acceleration reached its 48-G peak and began declining. This discontinuity inexplicably caused the integration routine to fail to converge properly, causing termination of the program.

The passive hydraulic energy absorber, although promising, requires uncertain new technology and could not be developed within this project to the extent necessary to fulfill the deliverable hardware requirements of the contract. The passive hydraulic energy absorber is not as suitable for retrofit as other systems, particularly because of its inherently small ratio of stroke to package length. After analytical feasibility had been demonstrated, no further development of the passive energy absorber was conducted.

6.3 CONSTRICKTION OF A TUBE

The fixed energy absorber loads for crewseats within the scope of this project are now provided by inversion tube energy absorbers.

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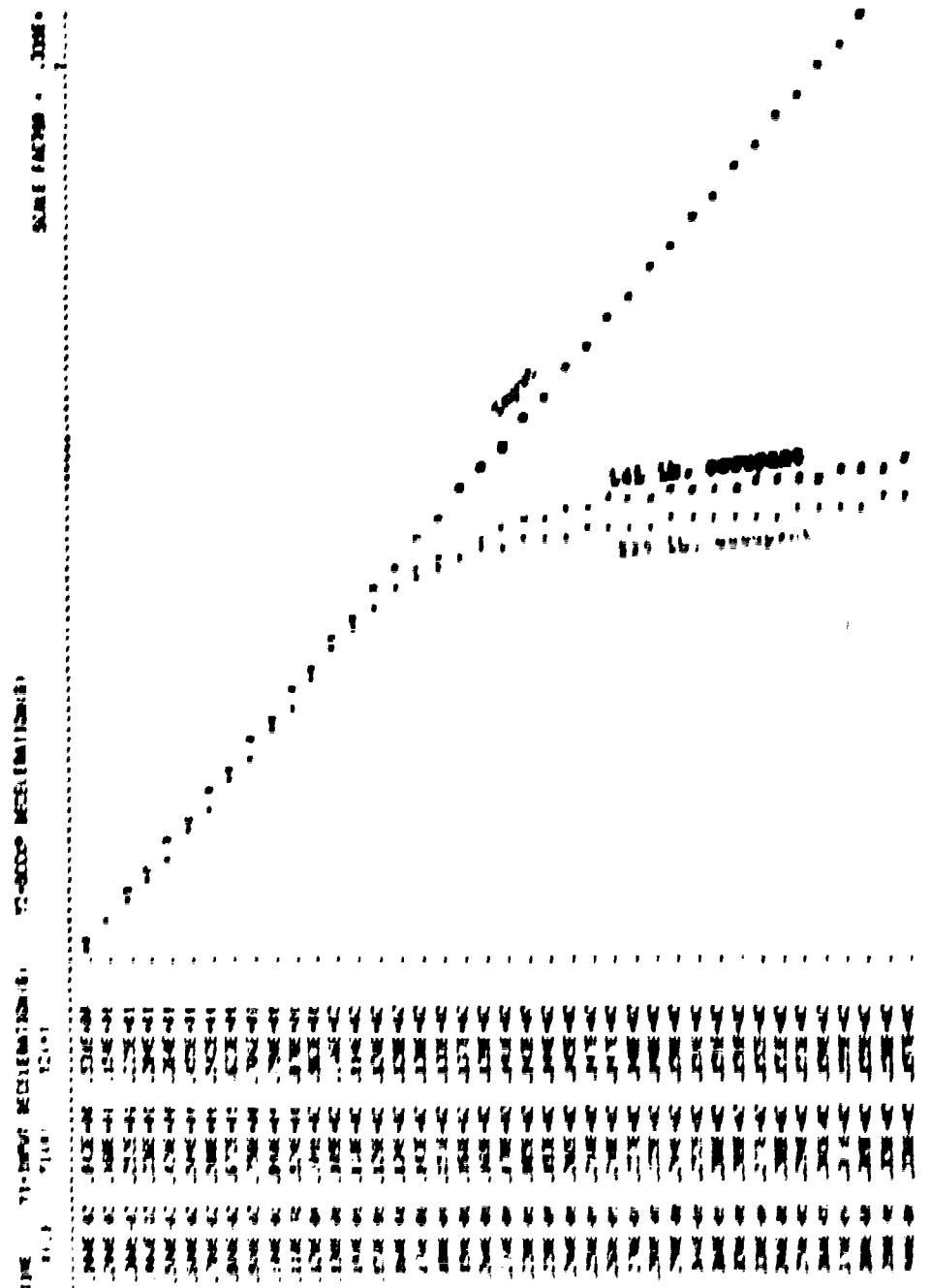


Figure 2. Polarization of two different sequences with order conditions being equal.

After inversion, the tube still retains enough ductility to allow it to be further plastically deformed. A constricting mechanism added to the inversion tube energy absorber was investigated for this purpose (see Figure 4). Testing in the early part of this program indicated that a roller mechanism, such as that shown in Figure 5, is capable of forming grooves in the inverted tube, thus creating enough additional load to satisfy the requirements of the variable portion of the required load. The inversion of the tube by itself provides the load required for the 5th-percentile occupant, and the constriction of the inverted tube can provide the varying degrees of additional load required for occupants up to the 95th percentile. This concept was found totally suitable for further development and is described in more detail in Section 7.0.

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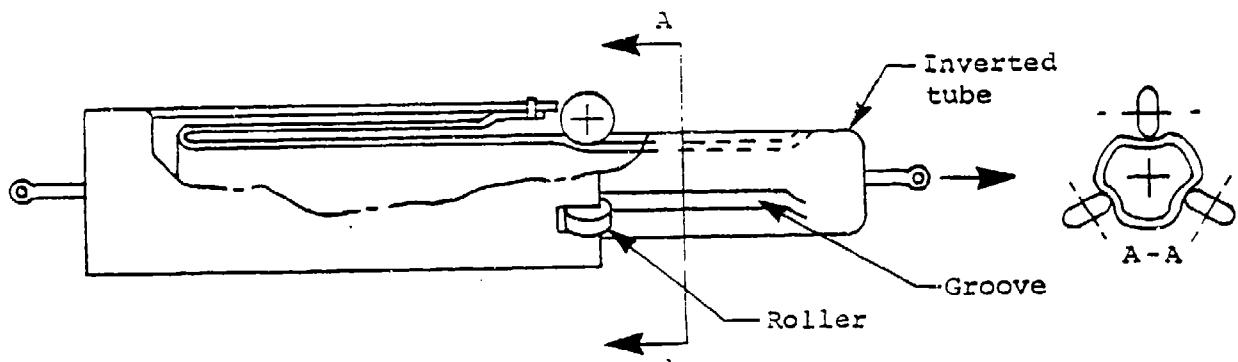


Figure 4. Rollers creating drag on inverted tube.

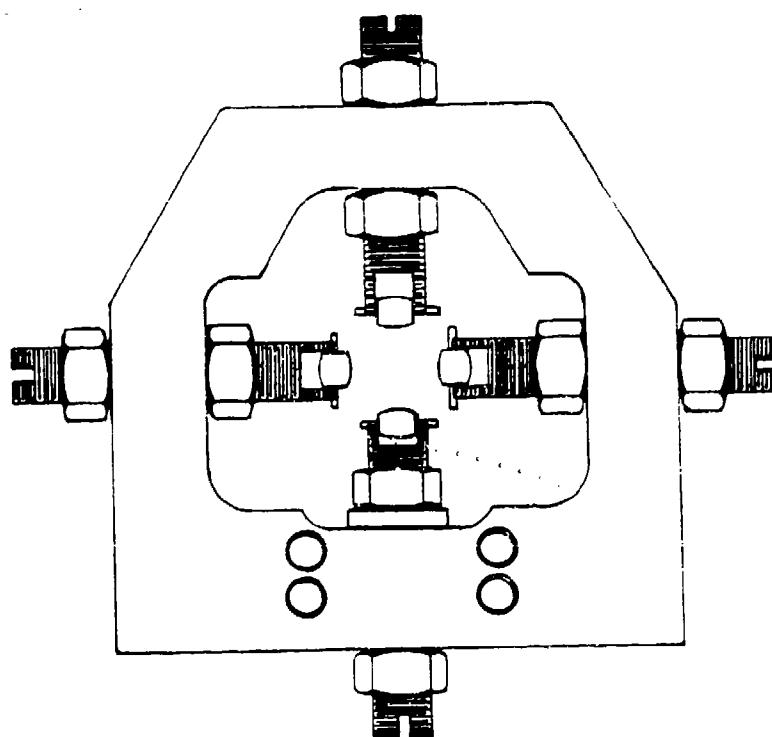


Figure 5. Roller test fixture (P/N SK10251-1)
used to investigate the load created
by pulling a tube between the rollers.

7.0 SELECTED DESIGN AND DELIVERABLE HARDWARE

7.1 GENERAL FEATURES

The variable-load energy absorber concept selected to be developed into deliverable hardware involves the constricting of the inverted tube of an ordinary inversion tube energy absorber. The final design concept is similar to that previously illustrated in Figure 4, except that spherical balls have been substituted for rollers. The balls make it possible to reduce the package size, complexity, and cost. Features of this system are as follows:

- The variable-load portion of the energy absorber uses a by-product of the fixed-load portion, thus economising on weight and cost.
- Stroking length of the variable-load portion of the energy absorber is inherently equal to that of the fixed-load inversion tube.
- Limit load can be infinitely adjustable for the vertical effective weight range of 127 to 193 lb.
- Adjustment can be performed through a compact, rugged mechanism.

The tube-constricting variable-load energy absorber can be adapted either to incremental adjustability or to infinite adjustability (over the weight spectrum of the 5th- through the 95th-percentile occupants). Infinite adjustability was provided on the deliverable hardware by coupling the energy absorbers to a remote control dial and to each other by means of flexible rotary shafts, as shown in Figure 6.

Actually, the device does not offer infinite adjustability, there being mechanical detents at only 10-lb. increments. However, the term infinite remains convenient to distinguish this system from a variation in which only three discrete increments cover the occupant weight range from 5th- through 95th-percentile.

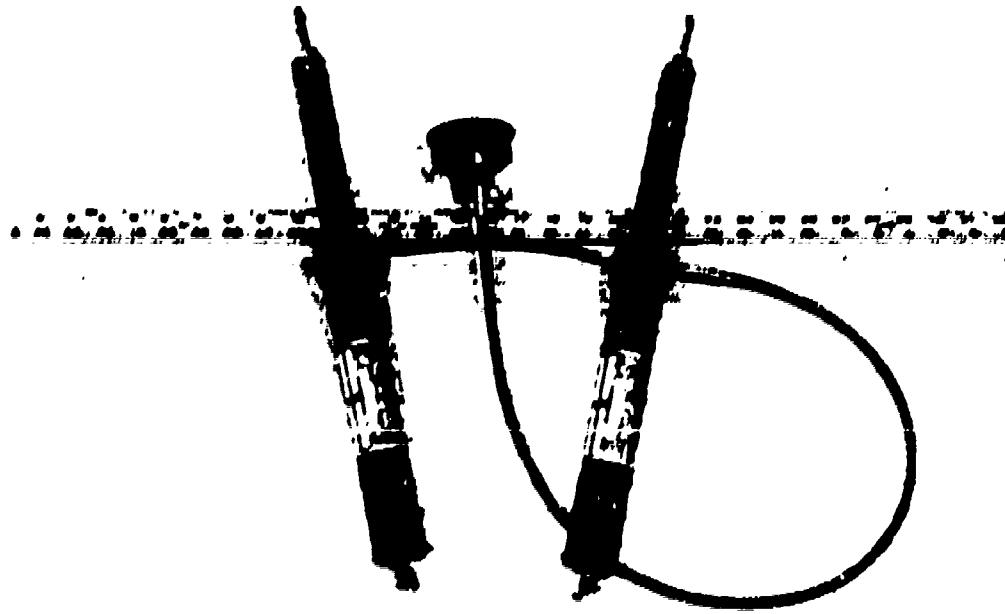


Figure 6. Variable-load energy absorbers connected to remote control dial by flexible shafts.

7.2 TUBE-CONSTRICTING MECHANISM

The tube-constricting mechanism increases the energy absorber envelope locally at the point where the inversion tube emerges from the housing as shown in Figure 7. The mechanism used to deform the inversion tube consists of six spherical balls, a ball retaining ring and a ball adjustment ring on each energy absorber as shown in Figure 8. Although more friction results from the use of balls than the rollers described in Section 6.3, the use of balls is justified by their greater simplicity. The spherical balls are guided within cross holes in the ball retaining ring, which is riveted to the energy absorber housing. The adjustment ring has six "cammed" or "ramped" surfaces which, as the adjustment ring is rotated, displace the balls either towards or away from the centerline of the inversion tube.

The rotational movement of the adjustment ring is accomplished by a worm gear segment attached onto the adjustment ring and is driven by a worm which, in turn, is rotated by a flexible shaft.

The worm and worm gear system was selected because of its inherent self-locking characteristics (i.e., the gear is not capable of driving the worm; the worm must drive the gear). This is important because the selected position of the adjustment rings must not be affected by reaction loads of the balls acting upon the ramped surfaces.

7.2.1 Preliminary Test

A breadboard test model of the deforming mechanism utilizing six spherical balls was built and tested. The adjusting ring was equipped with scribe marks at every 2 degrees, and the retaining ring with an index mark so that degrees of rotation could be easily recorded.



Figure 7. Increase in the energy absorber envelope where the inversion tube emerges from the housing.

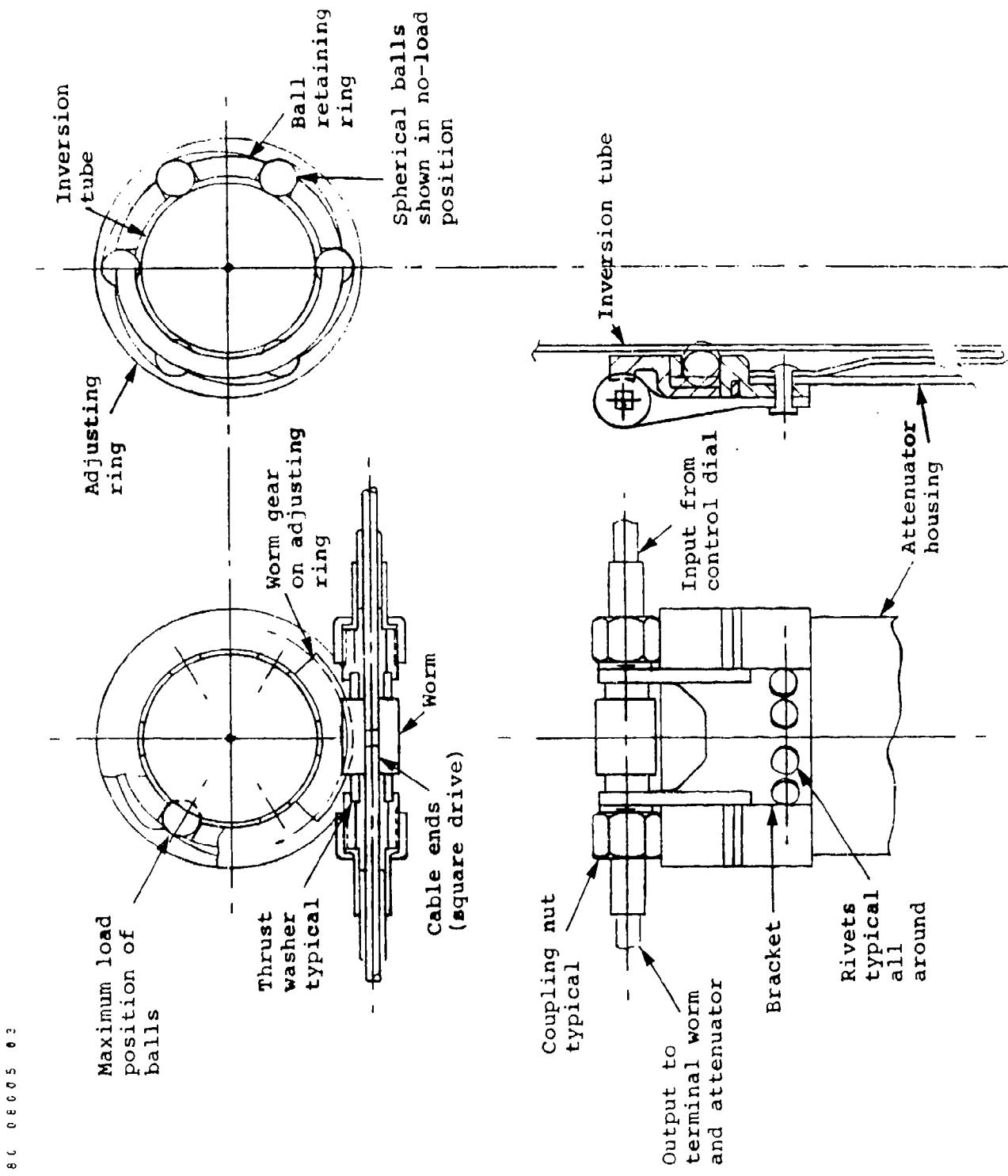


Figure 8. Tube-constricting mechanism added to inversion tube energy absorber.

A tube which had previously been inverted was then pulled through the test fixture with the hydraulic ram, as shown in Figure 9, at a rate of 1 to 3 in./min. For each increment of the adjustment rotation, the load was sensed by a load cell and displayed on a digital voltmeter. Figure 10 shows the fluted appearance of the tube following the test.

It would be desirable for the total variable load absorbed to be generated by the deformation of the inversion tube around the spherical balls; however, an additional load is created by the friction from the spherical balls rotating within the ball retaining ring and against the adjustment ring. The spherical balls, ball retaining ring, and the adjustment ring have no inherent provision for lubrication.

Because friction should be kept to a minimum, Teflon or graphite-type, etc. lubricant coating needs to be applied to the surface of the inversion tube. The coating must also provide corrosion protection. This coating can either be a dip or spray-on type, and must have the capacity to adhere to the tube surface as the tube is inverted during stroking. It is also undesirable for the coating to flake or peel off at the point where the spherical balls are deforming the inversion tube.

Teflon coating was chosen because it exhibits the best combination of properties meeting the above-mentioned requirements. Figure 11 shows the load-versus-rotation characteristics for both lubricated and unlubricated inversion tubes.

7.2.2 Incrementally Adjustable Control (Not Built)

A tube-constricting mechanism adapted to incremental control which would cover the occupant weight range in three discrete intervals was investigated on paper only; no hardware was built.

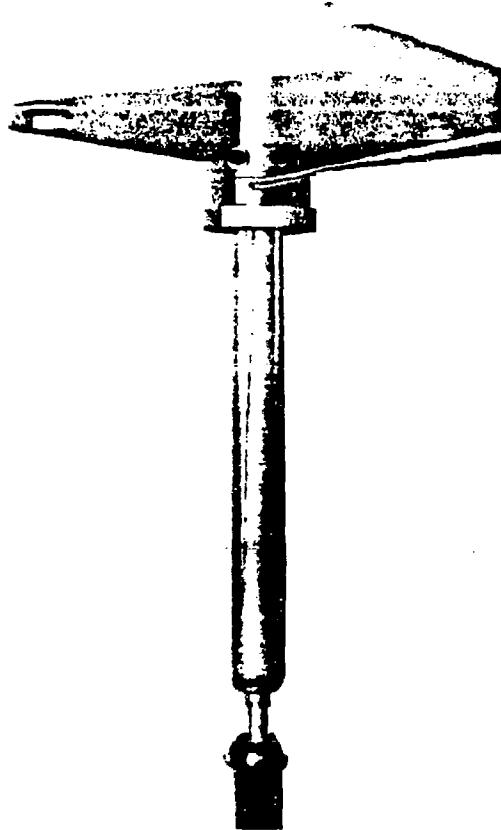


Figure 9. Breadboard testing of the deforming mechanism using a previously inverted tube.



Figure 10. Fluted (i.e. grooved) appearance of the inversion tube after breadboard testing.

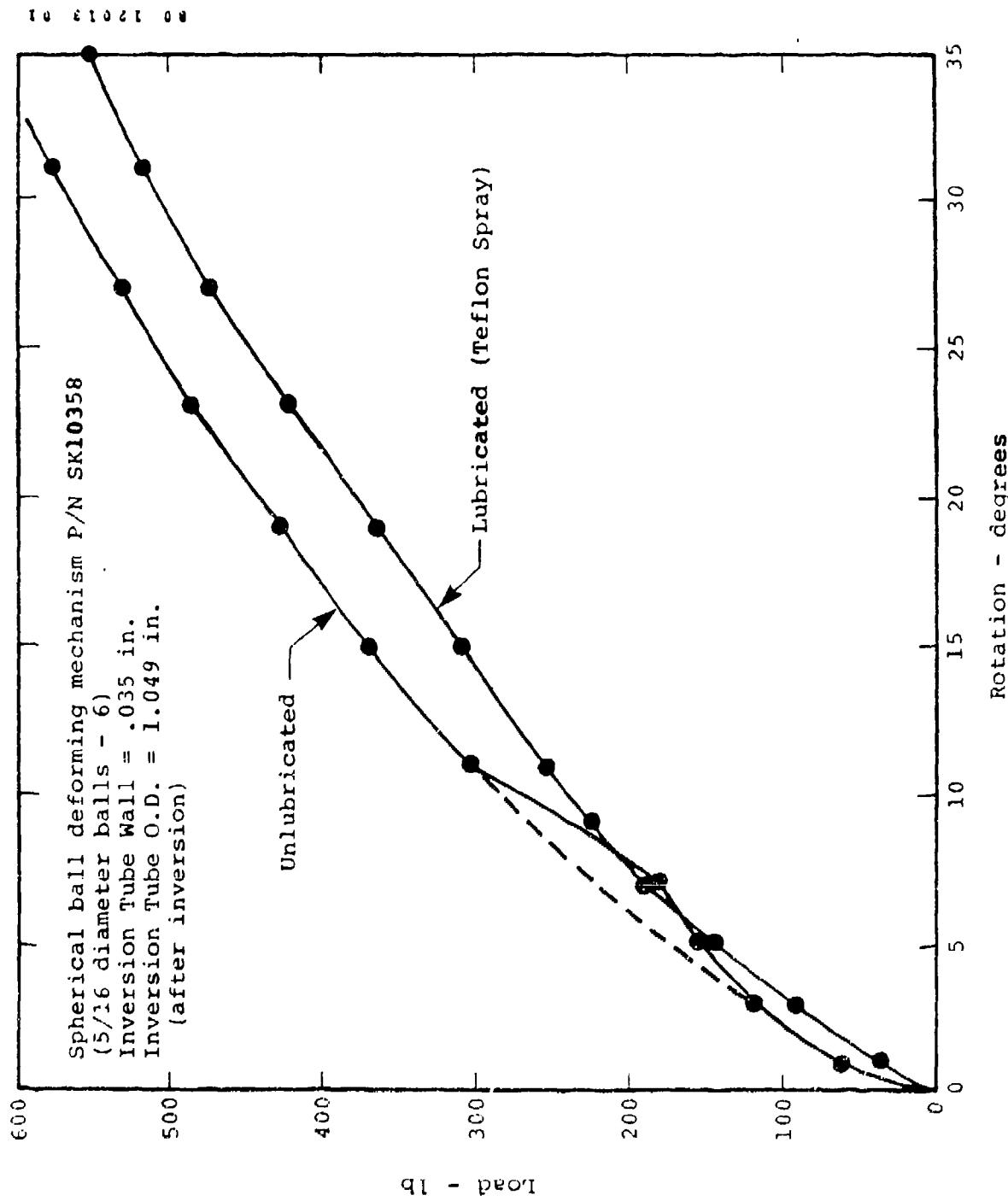


Figure 11. Influence of lubrication on load versus degrees of rotation.

As shown in Figure 12, it would share many similarities to the "infinitely" variable design. Major differences would include: the cam surfaces which govern the radial position of the balls having three steps rather than being continuous, a spring-loaded mechanical detent being required to position the steps to align themselves with the balls, and remote control being accomplished by a three-position lever mechanism similar to an inertia reel control handle.

7.3 REMOTE CONTROL MECHANISM

As previously described, the worm screw of one energy absorber is connected to the remote control dial by a flexible rotary shaft. **Another short flexible rotary shaft connects that worm to the worm of the other energy absorber.** In this manner both deforming mechanisms are positioned simultaneously and accurately by the control dial.

For test purposes the control dial was located on the bucket of an SH-60B Seahawk (LAMPS) crewseat adjacent to the right shoulder of the seated occupant as shown in Figures 13 and 14. The dial can be easily turned by grasping its knurled rim as shown in Figure 15. As the dial is turned, weight graduations engraved upon it appear in the window of the housing. An exploded view of the dial, housing, and cable connection can be found in Figure 16.

A ring gear on the dial drives a pinion gear on the flexible shaft with a 1:6 ratio. This permits the non-uniform spacing of the weight graduations to be contained within one turn of the dial, while, at the same time, the flexible shaft rotates through many revolutions. The multiple revolutions of the shaft are important for two reasons: first, angular deviations resulting from cable flexibilities are reduced to a small percentage of the total rotation, thus increasing signal transmission accuracy; second, the worm screws at the driven end of the flexible shaft require many turns to move the adjusting ring on the energy absorber.

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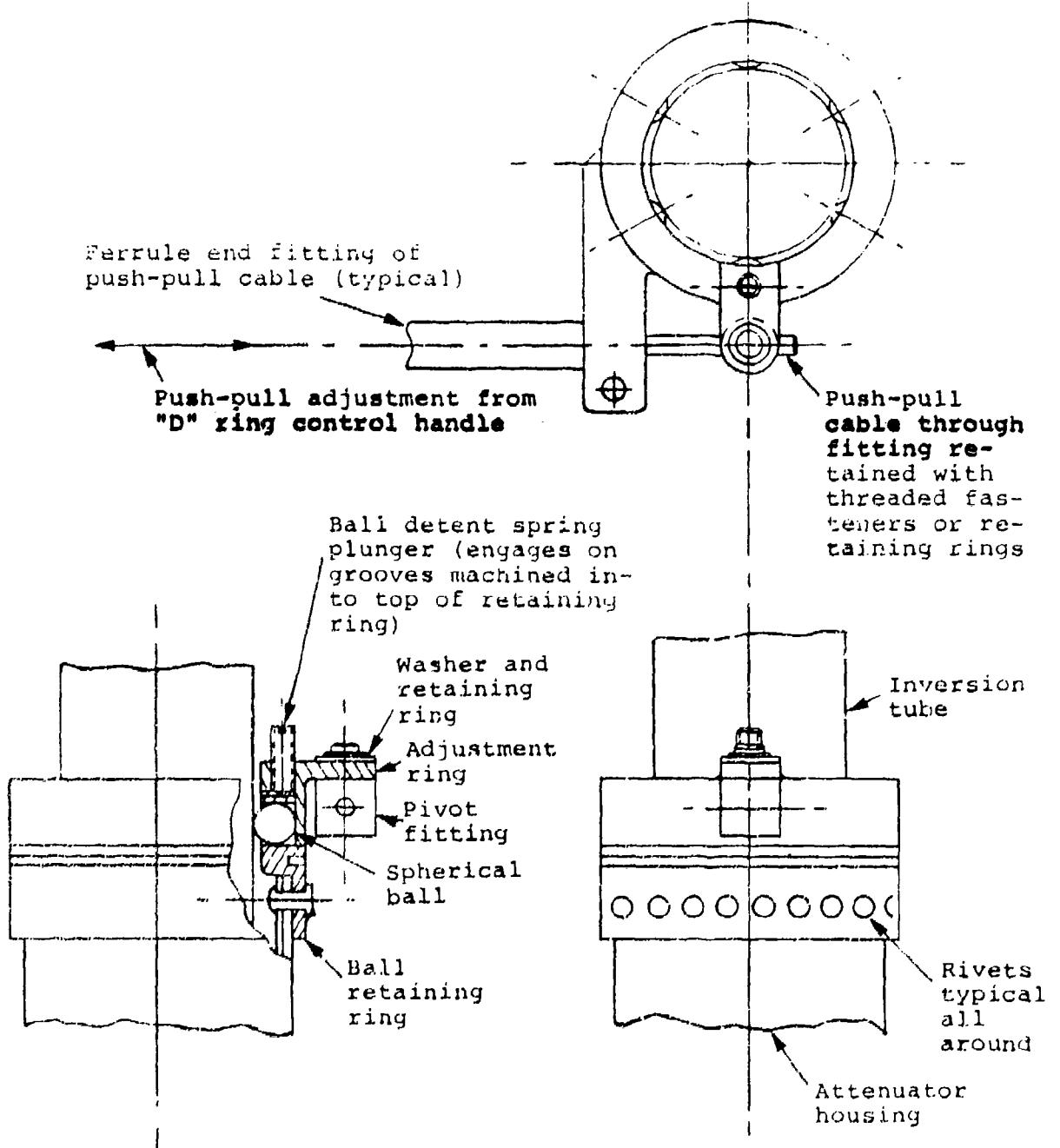


Figure 12. Incremental deforming mechanism on energy absorber.

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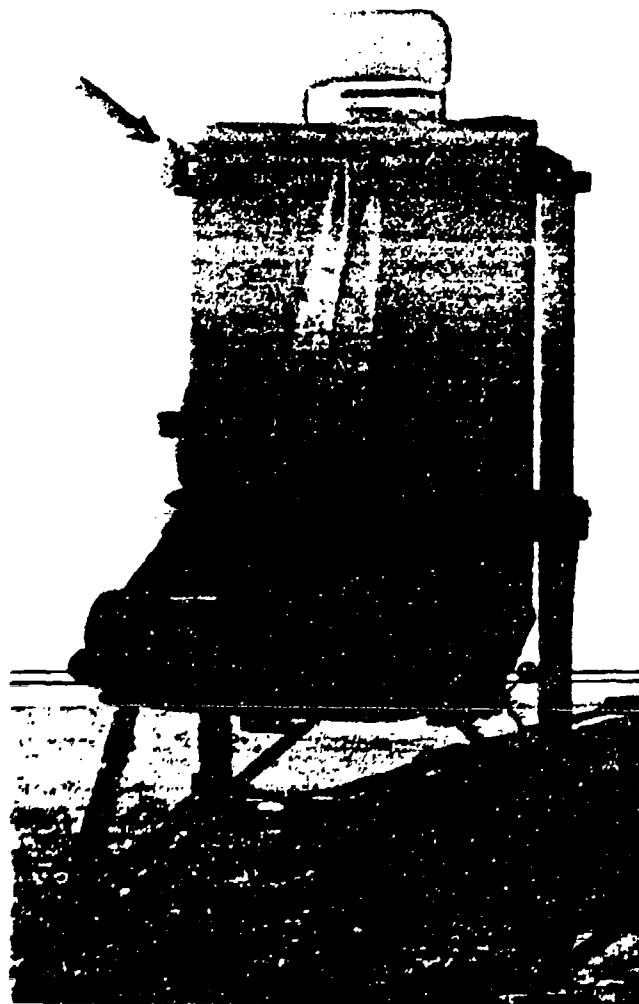


Figure 13. Control dial located adjacent to the occupant's right shoulder.

Figure 14. Close-up view of control dial location.



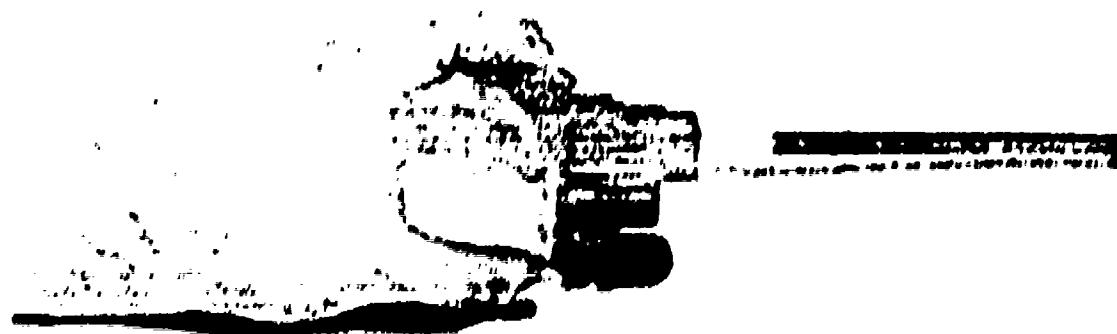


Figure 15. Rotation of the control dial is easily performed to allow the occupant to adjust the system for his estimated weight.

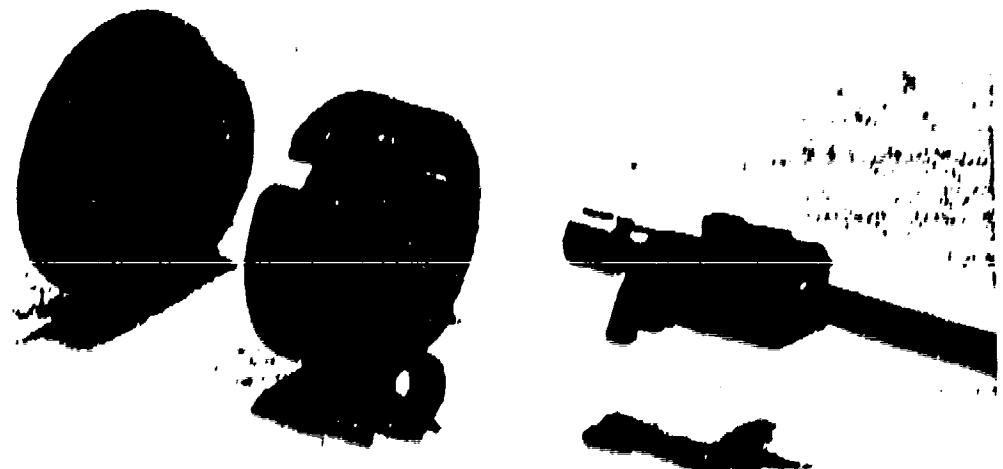


Figure 16. Exploded view of the control showing the dial, housing, and cable connection.

The preferred means of attaching the flexible shaft to the pinion gear is illustrated in Figure 17. The actual hardware attachment, as it appears in other photographs, differed in order to make use of more readily available flexible shafts.

7.4 CALIBRATION OF THE CONTROL DIAL

It was decided that the graduations on the control dial should display the total weight of the occupant plus the equipment carried on his body. Operator instructions explaining this are displayed on the control housing as shown in Figure 18. Graduations appear on the dial in 10-lb increments, and a spring-loaded mechanical detent holds the dial in place when one of those graduations appears in the window of the housing. Underlined numbers in the "Total Weight" column of Table 1 show the weight increments chosen to be displayed. The "Static Load Per E/A" column in the same table shows static energy absorber loads corresponding to each value in the "Total Weight" column.

A nonlinear relationship exists between control dial rotation and static load; therefore, the graduations cannot be placed at equal angular intervals around the control dial. Correct locations of the graduations on the dial were determined empirically by the following method. The variable-load energy absorber assembly was attached to a hydraulic cylinder and load cell as shown in Figure 19. The energy absorber was then stroked at a rate of 2 in./min. As the inversion tube was being stroked, the control dial was adjusted to achieve the largest precalculated static load reading from the "Static Load Per E/A" column of Table 1 as indicated by the load cell digital readout. The control dial was then marked to indicate 240 lb (see Table 1). The control dial was adjusted again (thus turning the adjusting ring on the energy absorber) to achieve the next lower predetermined load cell reading and the control dial marked, etc.

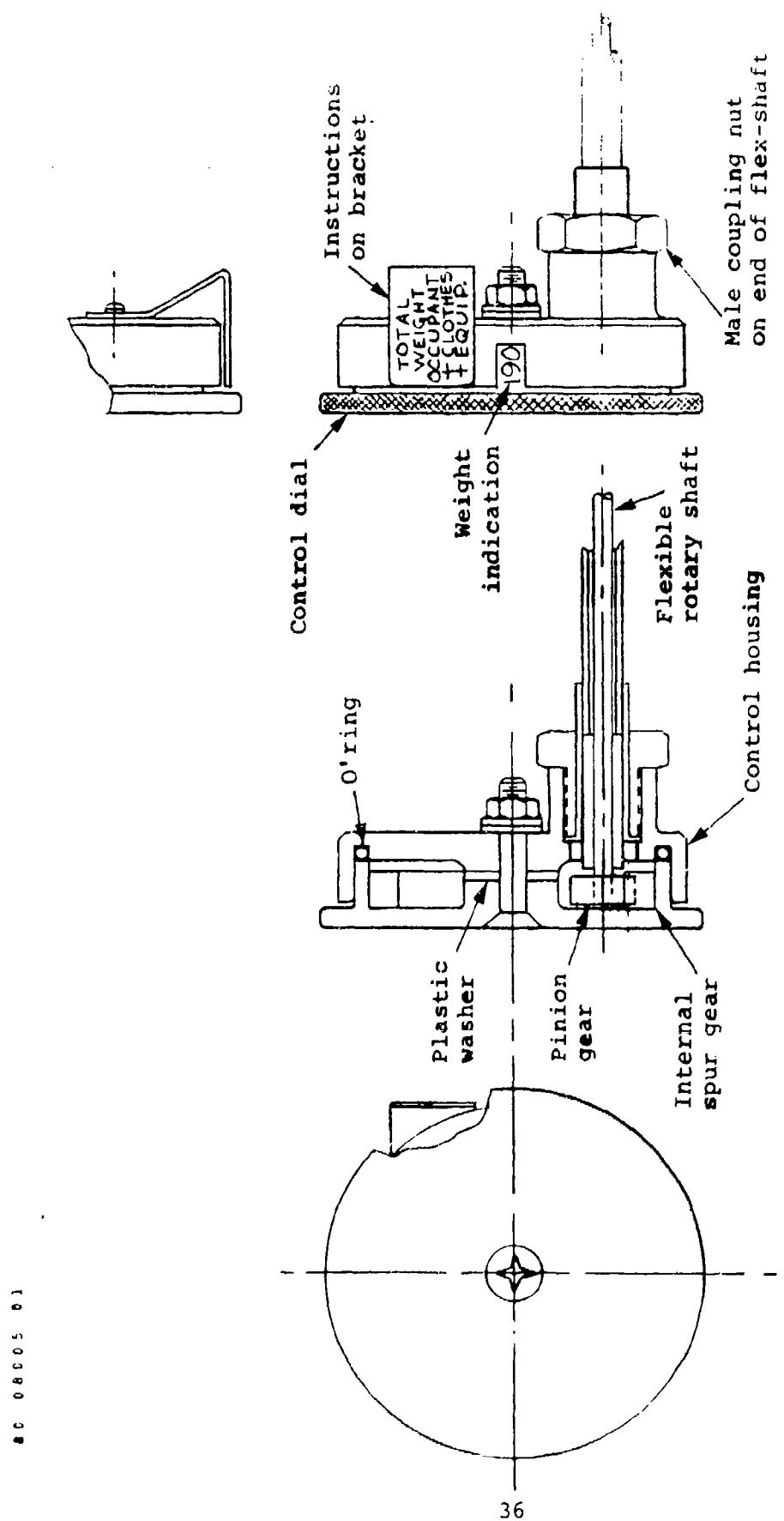


Figure 17. Control dial for the infinitely adjustable system for deforming the inversion tube with spherical balls.

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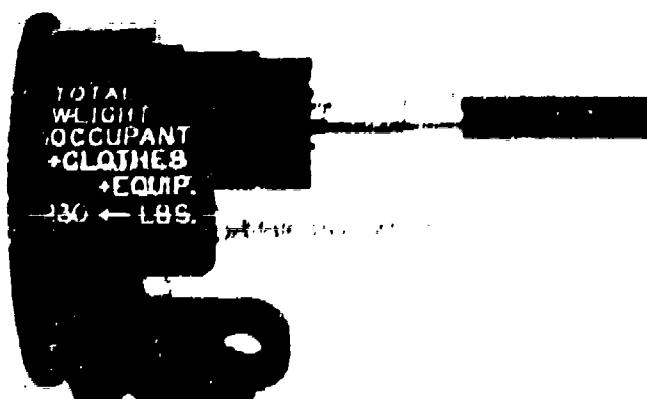


Figure 18. Operator's instructions displayed on the control housing.

TABLE 1. WEIGHTS USED TO CALIBRATE CONTROL DIAL

| Occupant, Clothing, and Equipment | ① | | ② | | ③ | | Comments |
|-----------------------------------|------------|------------------|------------------------------|-------------------------------------|---|-------------------------------------|----------|
| | Percentile | Nude Weight (lb) | Boots (W _b) (lb) | Total Weight (W _t) (lb) | Occupant Vertical Effect (W ^e) (lb) | Total Effect (W ^e) (lb) | |
| 5 | 140.3 | 3.4 | 4.1 | 152 | 119 | 142 | 1990 |
| 5 | 140.3 | 7.5 | 22.6 | 160 | 129 | 152 | 2130 |
| 5 | 203.6 | 7.5 | 22.6 | 170 | 137 | 160 | 2242 |
| 95 | 203.6 | 7.5 | 22.6 | 174.6 | 141 | 164 | 2294 |
| 5 | 140.3 | 7.5 | 22.6 | 180 | 145 | 168 | 2354 |
| 5 | 140.3 | 7.5 | 22.6 | 190 | 153 | 176 | 2466 |
| 5 | 140.3 | 7.5 | 22.6 | 200 | 161 | 184 | 2578 |
| 5 | 140.3 | 7.5 | 22.6 | 210 | 169 | 192 | 2690 |
| 5 | 140.3 | 7.5 | 22.6 | 220 | 177 | 200 | 2802 |
| 5 | 140.3 | 7.5 | 22.6 | 230 | 185 | 208 | 2914 |
| 95 | 203.6 | 7.5 | 22.6 | 238 | 192 | 215 | 3004 |
| 95 | 203.6 | 7.5 | 22.6 | 240 | 193 | 216 | 3026 |
| | | | | | | | 1573 |
| | | | | | | | 1368 |
| | | | | | | | 485 |
| | | | | | | | |

*Helmet, survival gear, and life preserver.

NOTES: 1. $W_e = .8 (W_t - W_{eq} - W_b) + W_{eq}$

2. Individual Dynamic Load per E/A = .5375 (total vertical force - 100 lb)...where 100 lb is correction factor for bucket guidance friction, and .5375 correction factor for geometry.

3. Individual Static Load per E/A = $\frac{\text{Dynamic Load}}{1.15}$ Dynamic Load Measured @ 20 ft/sec
Static Load Measured @ 2 in./min

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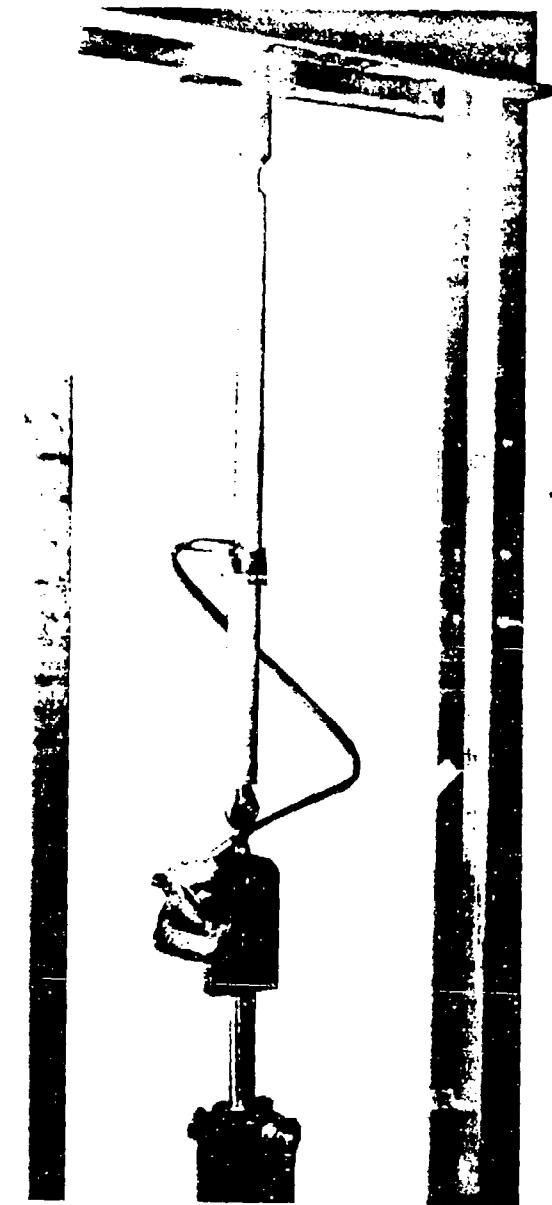


Figure 19. Test set-up for calibrating the control dial.

This procedure for calibrating the control is the most accurate way to ensure that the load generated by the variable-load device is in conjunction with the control dial reading. The dial, thus calibrated in conjunction with one variable-load energy absorber, is compatible with all similar energy absorbers manufactured to normal production tolerances. Similarly, any dial from a production run of dials whose graduations are spaced the same as the empirically determined dial would be compatible with any such production energy absorber.

7.5 PRECALIBRATION OF EACH VARIABLE-LOAD ENERGY ABSORBER

The following procedure was used to calibrate the tube-constricting mechanism of each energy absorber. The adjusting ring was rotated to bring all balls lightly into contact with the inversion tube (60 in.-lb torque) creating a no-load condition in which the steel balls will not deform the inversion tube as it strokes, thereby adding no additional load to the energy absorber. This no-load position was then permanently recorded by scribing a line on the housing adjacent to an index mark on the adjusting ring. The adjusting ring was then rotated to the angular position (found in previous testing) which permanently dents the balls into the tube slightly beyond that which is required to obtain maximum load. The adjusting ring was then turned to realign the scribe mark with the index mark. In this no-load position the deforming mechanism can be synchronized to the remote control dial, which itself is set to its minimum reading.

8.0 RETROFIT INSTRUCTIONS

8.1 ITEMS REQUIRED

The following is a list of items required to retrofit existing seats with variable-load energy absorbers:

- 2 - Variable-Load Energy Absorbers
- 1 - Deforming Mechanism Control with 36-in. long flexshaft attached
- 1 - Flexshaft (9.87 in.)
- 1 - Modified Spacer for Linear Bearing
- 2 - Worms
- 2 - Roll Pins (5/64 diameter)
- 1 - Coupling Shaft

8.2 RETROFIT PROCEDURES

1. Remove upper right-hand outboard linear bearing spacer.
2. Replace bearing spacer with modified spacer (see Figure 20).
3. Install control (with instructions facing seated occupant) and tighten bolt. Torque to 60-80 in.-lb. (see Figure 21).
4. Preassemble the energy absorbers. (This will be performed by the contractor.)

a. Left-hand energy absorber:

Turn the adjusting ring to align the scribed marks (see Figure 22). Install worm and 9.87-in. long flexshaft to the worm bracket and retain with the 5/64-diameter roll pin (see Figure 23).

b. Right-hand energy absorber:

Turn the energy absorber adjusting ring to align the scribed marks. Install the worm and shaft to the worm bracket and retain with the 5/64-diameter roll pin (see Figure 24).

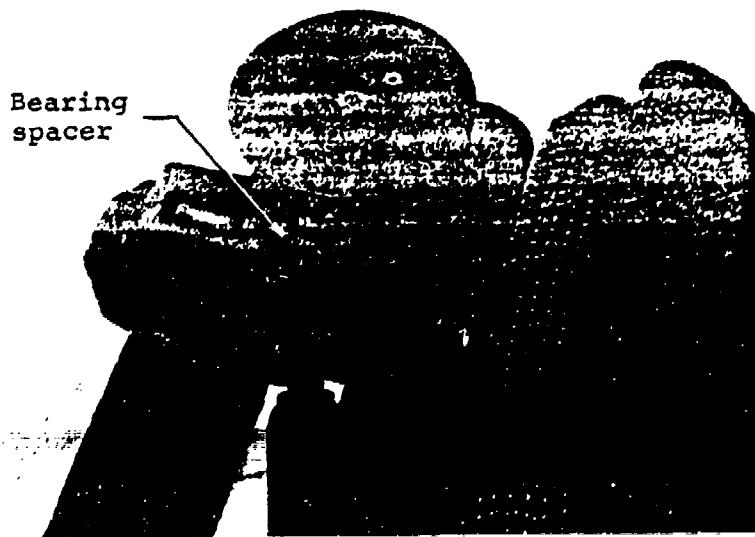


Figure 20. Modified bearing spacer replacement.

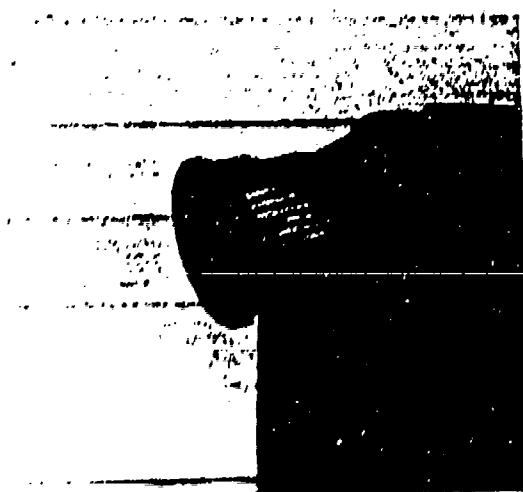


Figure 21. Mount control with instructions facing operator.

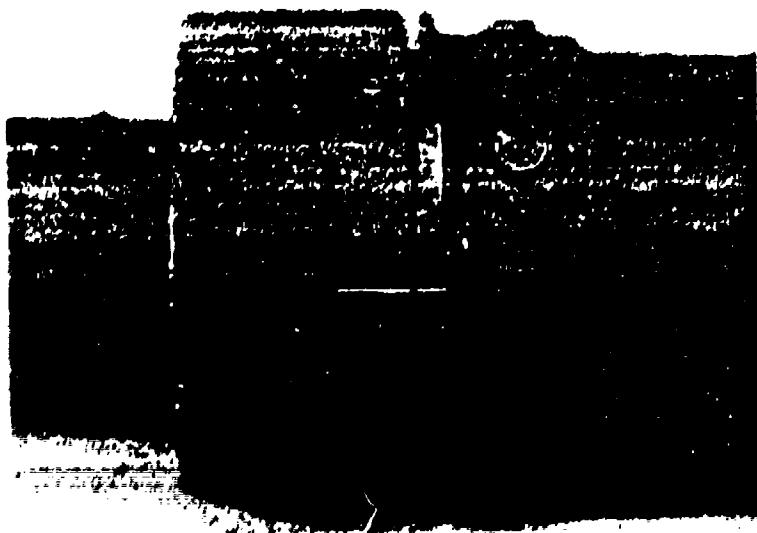


Figure 22. Turn adjusting ring to align scribe marks.

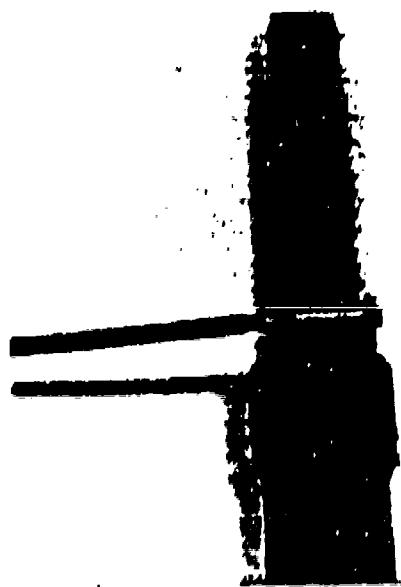


Figure 23. Left-hand energy absorber assembly with flexshaft and worm.

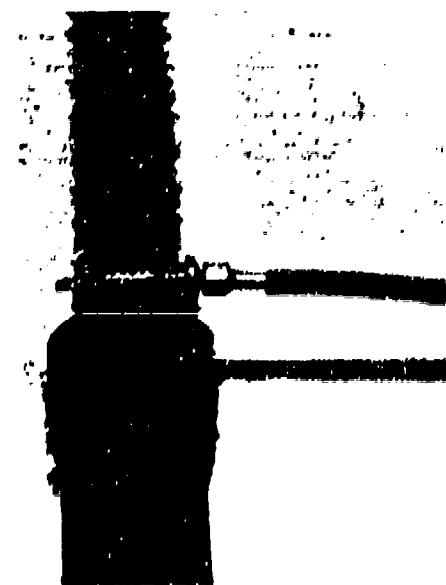


Figure 24. Right-hand energy absorber assembly with worm shaft and worm.

5. Remove existing energy absorbers and install variable-load devices with worm bracket towards seat bucket (see Figure 25).
6. Set control dial for 152 lb (i.e., total minimum occupant weight).
7. Check the alignment of the scribed marks. Turn worms if necessary to precisely align the marks.
8. Make a loop in the long flexshaft from the control, insert free end onto coupling shaft (end nearest control), and secure with set screw. Verify that control dial reads 152 lb when scribed marks on energy absorber are aligned.
9. Install short flexshaft (9.87 in. long) female end onto coupling shaft and retain with set screw.
10. Verify that, for a control dial reading of 152 lb, scribe marks on both energy absorbers are aligned.
11. Realign if necessary.

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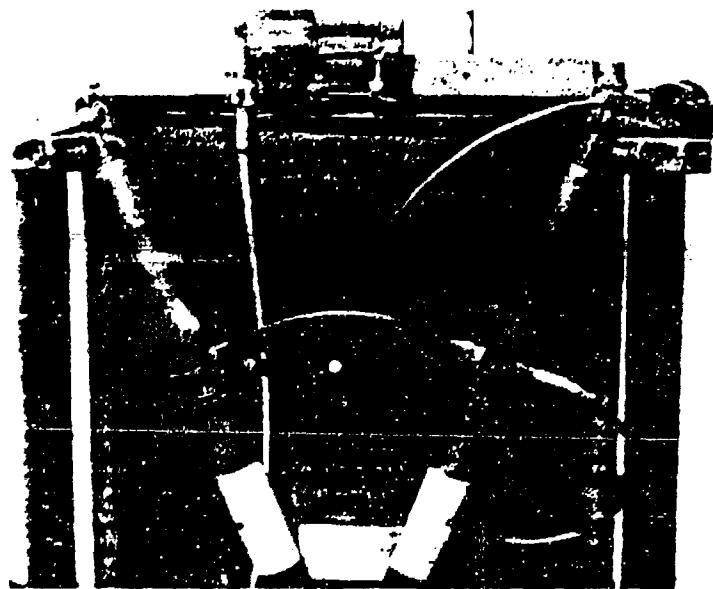


Figure 25. Variable-load attenuators installed on seat (worm bracket towards seat).

9.0 CONCLUSIONS

The objectives of the program, to design, develop, and test a variable-load energy absorber, have been achieved. The inversion tube energy absorbers, in conjunction with the tube-constricting mechanism and remote control, allow the occupant to select the limit load of an energy absorbing seat to correspond with his total weight. This is accomplished by having the occupant adjust the control dial to indicate his estimated weight, including clothing and equipment, a procedure which should be performed during the preflight check. Once the control dial is set for the occupant's weight, no further action by the occupant is required. The control dial has a detent mechanism which will prevent the control from moving due to vibrations during flight. Also, the worm and worm gear on each deforming mechanism are self-locking and require an input from the control to move. This is an important aspect because, as the energy absorber strokes, it is not acceptable for the load to change from the occupant's initial setting.

The control is a rugged and compact unit, which is easily accessible and is adjusted by sight. The instructions are clear and simple, thus reducing operator error. Rotary flexible shafts are used to transmit the motion from the control to the tube-constricting mechanisms on the variable-load energy absorbers. They transmit rotary motion in both directions accurately and consistently.

The variable-load energy absorber achieves its total load from two sources. The first is a fixed-load inversion tube energy absorber identical to the ones currently in use on the crewseats for which its use is intended, except that its limit load is set for the 5th-percentile lightly equipped occupant. The second source of load is variable and utilizes constriction of the already-inverted tube. Because the variable-load portion of the

energy absorber uses a by-product of the fixed-load portion, its stroke is inherently long enough, and weight and cost are minimized.

The overall package size of a fixed-load inversion tube energy absorber was not increased much by the addition of the prototype tube-constricting mechanism. In its production form, the tube constrictor could be even more compact due to integration of different components with each other. The variable-load energy absorber system, in its production form, would weigh only about 1 lb more than existing systems. The above-mentioned features indicate that the variable-load energy absorber and the remote manual control system meet the ultimate retrofit goals of the program.

10.0 RECOMMENDATIONS

Tests, including a drop test and evaluation by pilots of the control dial and its location, should be performed on the SH-60B crewseat. Data from testing and evaluation should be analyzed to identify possible improvements and to determine if further testing is required using the same variable system or a modification of this system.

Preliminary studies will be necessary to determine the variable energy absorber characteristics required for the UH-60A and AH-64A crewseats. Minor variations of the concept developed thus far will probably be necessary to serve the unique requirements of those seats. Different bucket weights, occupant weight ranges, energy absorber lengths, and stroking distances all have to be accommodated. Also, the location of the control dial and routing of the control cables will differ from those of the SH-60B because of differences in the seat configuration. A modification of the control dial will probably be necessary due to the mounting characteristics of the UH-60A and AH-64A crewseats. Additional tests and evaluation of the variable-load energy absorption system on the UH-60A and AH-64A crewseats will be necessary. A testing and evaluation schedule, similar to that for the SH-60B, should be established.

If the tests prove successful, then production design and cost estimation should be performed. A "value analysis" of the production design, including the selection of manufacturing methods, should be performed. For example, the prototype control dial and housing were completely machined (hogged-out). For production, these parts could easily be cast and have only the necessary features machined on them to reduce costs.

Following a final design review and approval by the branch of the armed services who will use the product, a vendor should be selected to initiate limited production of the variable-load energy

absorber. Additional drop tests and flight evaluation may then be desired. After the final testing and flight evaluation, a **full production and retrofit program could be initiated.**

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